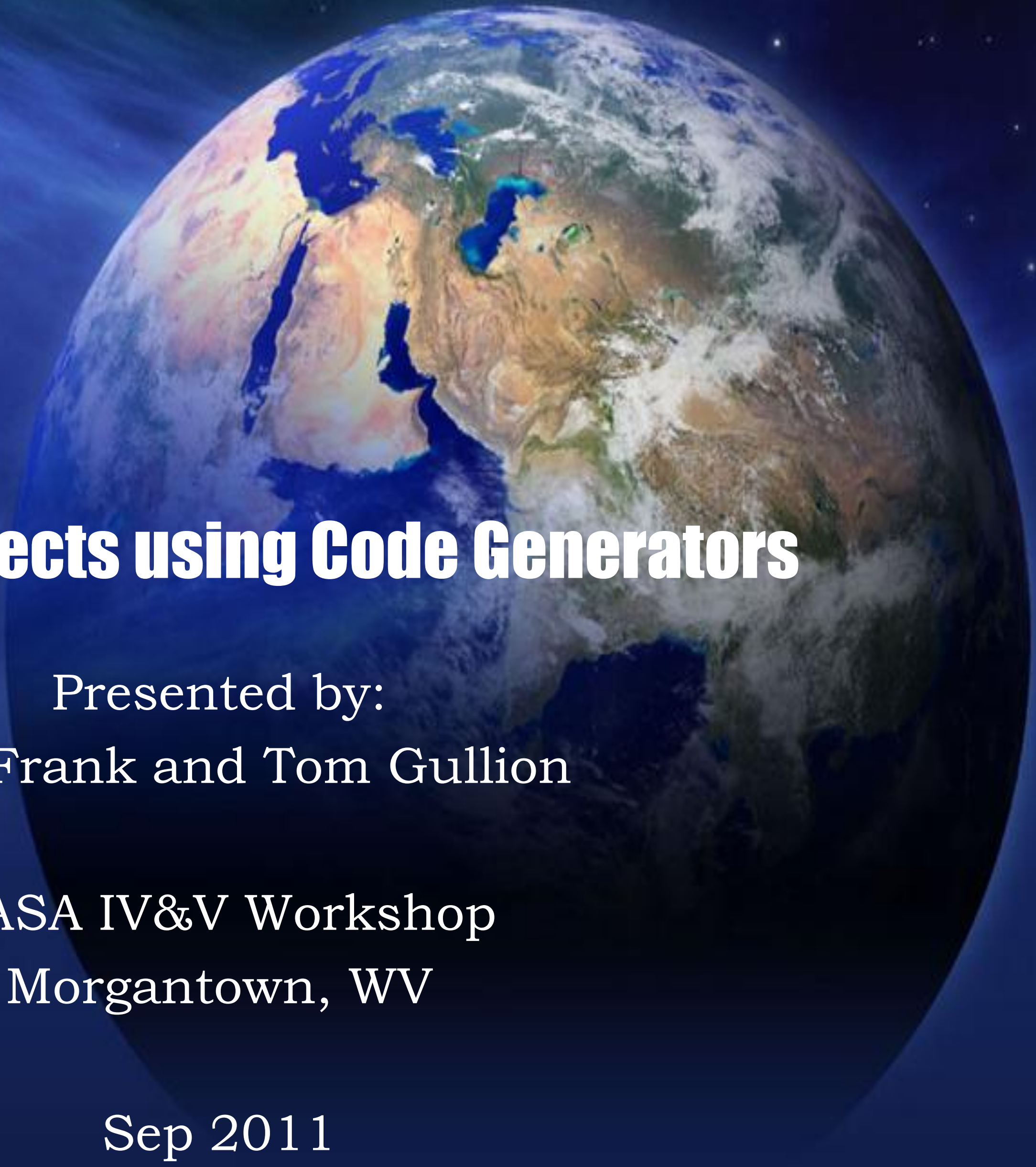

IV&V for Projects using Code Generators

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Emergent Trend

- In recent years, NASA projects have begun using generative programming approaches
  - At least one high-profile project ultimately abandoned this approach
  - Others seem poised to be successful (but are still in development)
- This presentation is not an endorsement of generative programming, but rather a survey to hopefully benefit IV&V

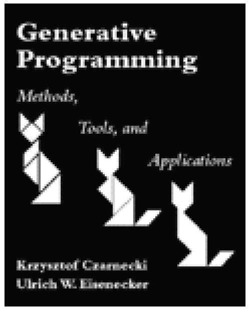
Code Generators Benefits

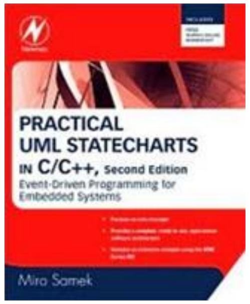
- Minimize Risk
- Enforce use of best practices, standards and guidelines
- Higher Quality
  - Avoid traditional, manual coding errors
- Highly Optimized
  - Single-purpose
  - Specialized
- Consistency
- Increased Productivity
- Extensibility
- Reuse
- Predictable Code

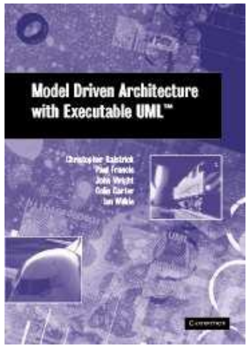
(not a complete list, nor in any particular order)

Modern Code Generation Background

- Generative Programming “Black and White Book”
  - Feature modeling
  - Component libraries and frameworks
  - Focus on configuration knowledge
  - Simplify interfaces
- Practical UML Statecharts
  - Event-driven
    - Useful for lower power consumption
  - Good for embedded systems
  - Includes open source generator
- Model Driven Architecture with Executable UML
  - Comprehensive approach
  - Antiquated?
- Eclipse ecosystem: JMerge, JET, others
- Many, many others…




PRACTICAL UML STATECHARTS IN C/C++, Second Edition
Event-Driven Programming for Embedded Systems
Miro Samek



Typical Code Generation Approaches

- Structured document as source
  - aka Textual Domain Specific Language (aka External DSL)
  - Structured document might be XML or CSV
- UML model as source
  - Often using one or more UML Profiles and Action Languages
  - NOT Model-Driven Architecture (MDA)
    - Usually only generating parts of a larger system
- Commonly used for controller code

- Internal DSL or Fluent Interface
  - Libraries which morph syntax into domain specificity
  - Not really code generation, but a recent, related trend
  - Example:

```
manager.newCommand().with(4, "SYS").with(5,
  "DAT".optional().priorityLow();
```

Code Generator Inputs (Activities)

- Original approach was often a flowchart
  - Rather weak
    - Leads to inefficient, redundant, inherently procedural code
- Benefits of UML Activities
  - Standard UML2 syntax
  - Component and OO paradigm support
  - Code generation concepts included in metamodel
    - Control Flows
    - Object Flows
    - Tokens
  - Tools provide model audit / model checking capabilities
  - Extensible via UML Profiles
    - Optimize for special purpose
    - Influence generated code
  - Action Language support
- Challenges of UML Activities
  - Standard UML2 Syntax is bloated
  - Foundational Subset for Executable UML Models (fUML) helps

Code Generator Inputs (State Machines)

- Benefits of UML State Machines
  - Standard UML2 Syntax
  - Simple graphical model
  - State machines well-known
    - Harel Statecharts
  - Transform to/from textual representation
  - Tools provide model audit / model checking capabilities
  - Extensible via UML Profiles
    - Optimize for special purpose
    - Influence generated code
- Challenges of UML State Machines
  - Standard UML2 Syntax is bloated
    - Supports multiple kinds of statemachine: Mealy, Moore, Harel, etc.
  - Several "standards" to choose from

Challenges for Traditional V&V (1 of 2)

- Static Code Analysis of little use on generated code
  - Complexity metrics not applicable
  - Maintainability metrics not applicable

- Holzmann's Power of Ten Audits (http://spinroot.com/p10/)

⊗ 1. Restrict to simple control flow constructs.
? 2. Give all loops a fixed upper-bound.
? 3. Do not use dynamic memory allocation after initialization.
⊗ 4. Limit functions to no more than 60 lines of text.
⊗ 5. Use minimally two assertions per function on average.
⊗ 6. Declare data objects at the smallest possible level of scope.
⊗ 7. Check the return value of non-void functions, and check the validity of function parameters.
⊗ 8. Limit the use of the preprocessor to file inclusion and simple macros.
⊗ 9. Limit the use of pointers. Use no more than two levels of dereferencing per expression.
? 10. Compile with all warnings enabled, and use one or more source code analyzers

⊗ Not applicable to generated code ? Ensure generator enforces

Challenges for Traditional V&V (2 of 2)

- Varying approaches and/or specifications
  - Projects sometimes use several code generators
  - Textual specification usually requires manual inspection
    - Automation possible if text is sufficiently structured
  - Model specification can be automated
- Change in V&V Methods for code inspections
  - Manual inspection of generated code of dubious value
  - Automated, static inspection of generated code of dubious value

Challenges for IV&V (1 of 2)

- Multiple code generation schemes and/or tools
  - Challenge for IV&V to cover multiple code generators
  - Additional work to thoroughly understand multiple code generators
- Access to code generator(s)
  - Timely access to the code generator is essential
  - Quality of IV&V is hindered if we must rely on the generated code only
- Integration approach
  - How is the project integrating generated and manual code?
    - Dependency analysis
    - Clear "Separation of Concerns?"
    - Low Coupling and High Cohesion?

Challenges for IV&V (2 of 2)

- Requirement traceability
  - Difficult, if not impossible, to trace from generated code back to originating requirement(s)
- Change in V&V Methods for code inspections
  - Manual inspection of generated code of dubious value
  - Automated, static inspection of generated code of dubious value
- Compare locally generated code against release version
  - Catch any post-code generation, well-intended “hacks”

Benefits for IV&V

- Input model analysis
  - Automated
    - if IV&V has the model and the modeling tool
    - Or, if IV&V can transform the model
- Extend code generator for IV&V purposes
  - One of the lurking benefits of code generators is the ability to use the same input to generate multiple outputs
    - Customize generator for a different language (e.g., C, C++, Java, PHP)
    - Customize generator for local test environment
    - Customize generator for Q2 and Q3 handling
- Reuse previous IV&V results against reused code generator

Code Generator Certification?

- Compilers
  - Originally, compiler output is not trusted
  - After testing and certification, compiler output is trusted and, importantly, *becomes a V&V tool*
- Code generators are similar to compilers
  - Certification of a code generator would enable its use as a V&V tool
  - Write code generator unit tests
    - Enable IVV-specific analyses
      - Q2 and Q3 handling
      - Non-functional requirement evaluation
  - Extend code generator with instrumented output
    - Enable IVV-specific analyses
      - Q2 and Q3 handling
      - Non-functional requirement evaluation

Certifying a Code Generator

- IV&V mini-project to "certify" a code generator
- Goals
  - Identify design constraints and/or assumptions encapsulated in the code generator
    - Memory management, array handling, indexing, etc.
    - Fault Handling
    - Off-nominal behavior (Q2 and Q3)
    - Etc, etc
  - Understand implications of input model and effect on generated code
  - Assemble audits for input model for quality and completeness checking

Room for Improvement

- Design Patterns for input models
  - Library of well-formed StateMachines for general purpose components
  - We see reuse of code generators
    - But not reuse of input models
- NASA IV&V library of code generators
  - Internal reference library of known code generators
    - Including test suites and model audits
  - Facilitate knowledge transfer across organization
  - Useful for subsequent projects

Summary

- Find out which code generation approach is being used
  - Answers many basic questions
  - Helps to focus the IV&V efforts
- Exert more analysis effort on input models
  - Watch for generator's "assumptions"
    - Memory allocation / releasing strategies
    - String lengths / limits
    - Array handling
    - Fault handling
    - Extended language features
    - Conformance to applicable standards and regulations
- Complications when tracing design to implementation
  - Some "design" features are implemented within the code generator
    - They may not necessarily conform to the published project standards or design constraints

Thank you!